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Ultraviolet Spectra of Two Magnetic
White Dwarfs

and

Ultraviolet Spectra of Subluminous Objects Found
in the Kiso Schmidt Survey

and

Ultraviolet Absorptions in the Spectra of DA White Dwarfs

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MAGNETIC WHITE DWARFS AND ULTRAVIOLET
SPECTRA OF SUBLUMINOUS OBJECTS FOUND IN THE
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ABSTRACT

The research work connected with Grant NAG5-287 from the National Aeronautics and Space Administration has been to carry out a number of projects in conjunction with the International Ultraviolet Explorer (IUE) satellite. These included: (1) studies of the ultraviolet spectra of DA white dwarfs which show quasi-molecular bands of H_2 and H_2^+ , (2) the peculiar star HR6560, (3) the ultraviolet spectra of two magnetic white dwarfs that also show the quasi-molecular features, (4) investigations of the ultraviolet spectra of subluminous stars, primarily identified from visual wavelength spectroscopy in the Kiso survey of ultraviolet excess stars; some of these show interesting metal lines in their ultraviolet spectra, and (5) completion of studies of the ultraviolet spectra of DB stars. The main result of this research has been to further knowledge of the structure and compositions of subluminous stars which helps cast light on their formation and evolution.

I. INTRODUCTION

The research funded by Grant NAG5-287 through the National Aeronautics and Space Administration in conjunction with the International Ultraviolet Explorer Satellite (IUE) was designed to make studies of the atmospheres of white dwarf stars and further peculiar ultraviolet excess stars in order to ultimately obtain information on the late stages of stellar evolution. These projects can be broken down into the following categories: (1) ultraviolet absorptions in the spectra of the cooler DA white dwarfs which are now known to be caused by the quasi-molecules of hydrogen, (2) studies of ultraviolet excess stars found from published ground based surveys, particularly those in the Kiso ultraviolet excess survey, (3) one particularly interesting star, K789-37, was found that shows numerous metallic lines in its ultraviolet spectrum, (4) ultraviolet spectra of two magnetic white dwarfs that also show strong ultraviolet absorptions, (5) the peculiar star HD159870 which was shown from the IUE observations to be composite, and (6) search for carbon in the spectra of DB white dwarfs. The main results of these investigations are described in the following sections.

II. THE DA STARS

In earlier studies sponsored by NASA Grant NAG5-287, it was found using the IUE that two strong absorption features appear in the ultraviolet spectra of the DA white dwarfs near the wavelengths of 1400 and 1600 Å. The origin of these features was shown in Nelan and Wegner (1985) to be due to the H_2^+ and H_2 quasi-molecules. The purpose of the most recent series of observations, to be described here, was to obtain ultraviolet spectra of a larger number of DA stars covering the range of effective temperature where the quasi-molecular bands are prominent and to interpret these data in the same manner as reported in Nelan and Wegner (1985) using model atmospheres.

Some examples of the SWP short wavelength low resolution IUE spectra of the DA stars are shown in Figure 1 where they are arranged approximately in order of decreasing effective temperature, hottest at the top of the diagram and coolest at the bottom. The range in effective temperature covered in this display of spectra is approximately 20,000 K to 8000 K.

In conjunction with these observations and an archive project with IUE data that is now being carried out here, a grid of pure hydrogen DA white dwarf atmospheres has been computed in collaboration with E. P. Nelan using the model atmosphere program LUCIFER which is specifically set up to include the ultraviolet quasi-molecular spectral features. Examples of the emergent spectral energy distributions for some of these models are shown in Figure 2 where the range covered in effective temperature brackets the observations shown in the earlier diagram. In comparing Figures 1 and 2, it should be noted that the theoretical fluxes shown in the second diagram cover the infrared through the ultraviolet and hence span a much wider range in wavelength than those observed, in Figure 1. The corresponding overlapping wavelength regimes are 1200-2000 Å in Figure 1 and $1/\lambda = 8.0-5.0$ in Figure 2. These serve to illustrate the behavior of the quasi-molecular features as a function of effective temperature well, although for all models, a constant surface gravity of $\log g = 7.6$ was used and a slightly higher value of 7.9 seems more appropriate for most DA stars.

III. THE KISO ULTRAVIOLET EXCESS STARS

Ground based spectroscopy of a sample of about 1200 ultraviolet excess stars being done at Dartmouth using the McGraw-Hill Observatory telescopes (Wegner and McMahan 1985, 1986; Wegner et al. 1987a,b) have produced a list of numerous interesting faint blue objects that can be observed in the ultraviolet with the IUE. The list of objects to be studied was originally produced in Japan using the Kiso Schmidt telescope and published by Noguchi et

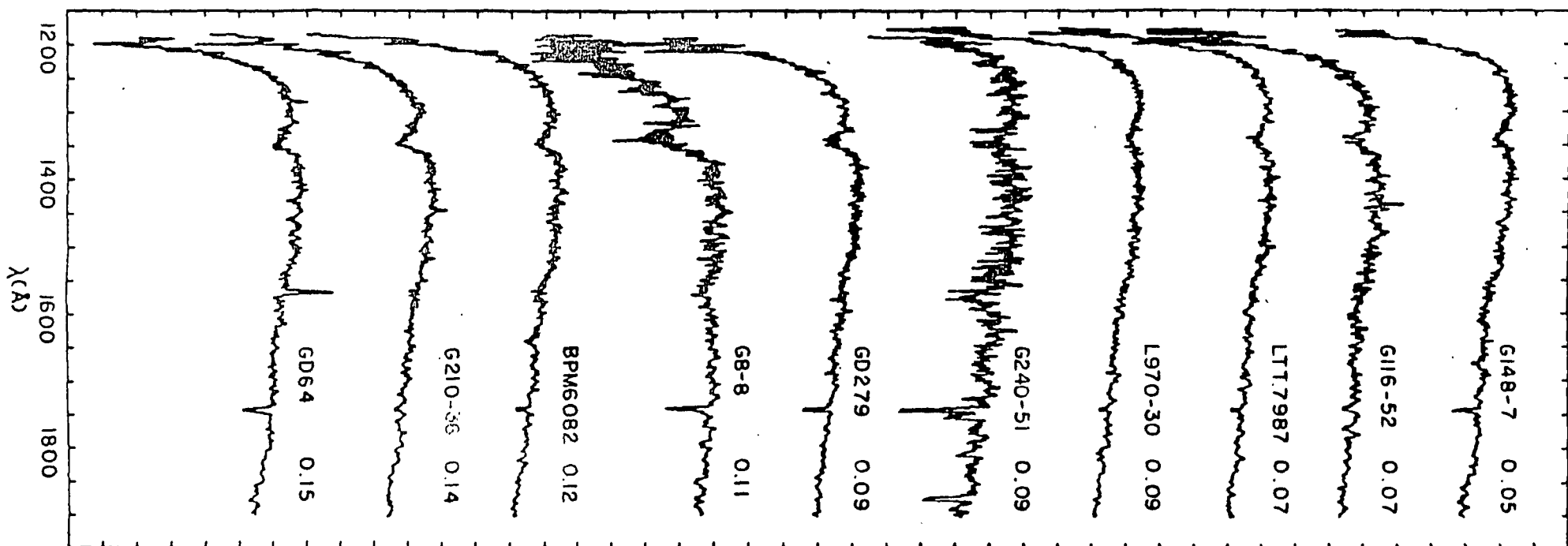


FIGURE 1 - Examples of the SWP spectra of several recently observed DA white dwarfs.
The number to the right of the star's name is the published (B-V) color index.

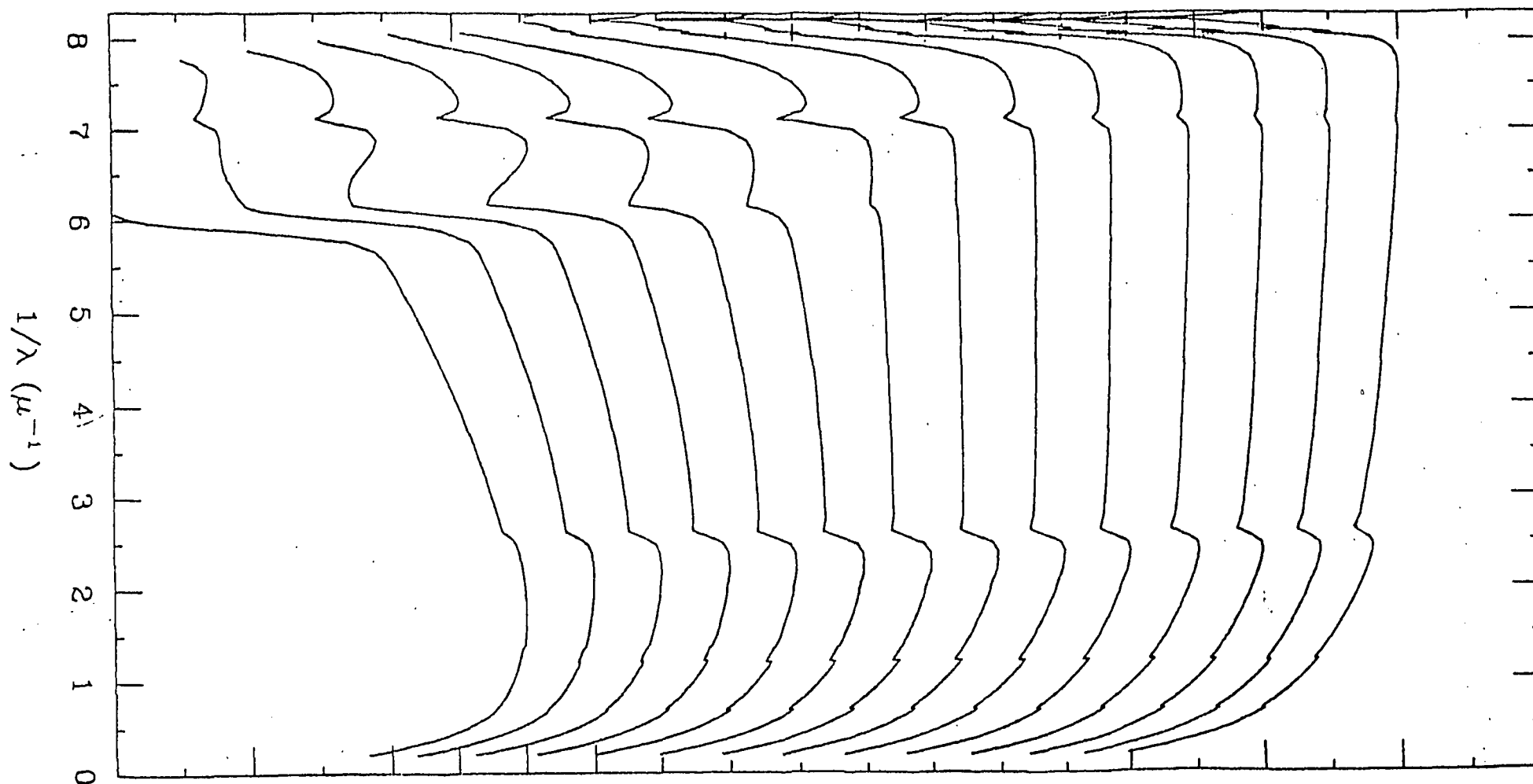


FIG. 2 - Emergent spectral energy distributions for DA white dwarfs calculated from model atmospheres, to be compared with Figure 1. All models had a pure hydrogen composition and surface gravity $\log g = 7.6$. The run in temperature is from 21000K (top) to 8000 K (bottom). Of note are the strong ultraviolet absorptions near $1/\lambda = 7.1$ and 6.2 corresponding to the features near 1400 and 1600 Å respectively in Figure 1.

al. (1980) and Kondo et al. (1984). The ultraviolet and visual portions of one of these stars, $V = 17.0$ mag. KUV1584-0939, are shown in Figure 3. In the visible portion of the spectrum, this object shows a strong blue continuum and marked He II emission lines as well as features in emission at the positions of the hydrogen Balmer lines which could be due to either H or He. A number of similar objects have been found and observed with the IUE and observations of this type are useful for sorting out the physical nature of objects like this.

IV. ULTRAVIOLET METAL LINES IN DZ WHITE DWARFS

Figure 4 shows another example of one of the kind of objects studied in this investigation. This is an example of a rare DZ type white dwarf named K879-37, also known as PG12252-0757, which was first shown by Kilkenney (1986) to belong to this spectral class using ground based spectroscopy. This star's atmospheric composition is being analyzed in collaboration with D. Koester at Louisiana State University. The IUE observations show that this star's ultraviolet spectrum is rich in metallic lines and thus appears to be an interesting clue for studying accretion and mixing processes in the atmospheres of white dwarfs.

V. ULTRAVIOLET SPECTRA OF MAGNETIC WHITE DWARFS

The majority of the DA white dwarfs that have been studied for the presence of the 1400 and 1600 Å quasi-molecular bands have not shown the presence of magnetic fields. However, two magnetic white dwarfs also show the presence of these features. The low resolution mode SWP spectra from the IUE of these stars known as BPM25114 and K813-14 are shown in Figures 5 and 6. Both of these stars have over all spectral energy distributions indicating effective temperatures near 10,000 K. However, compared to the non-magnetic DA stars of similar effective temperature, the profiles of the ultraviolet absorptions appear to be deeper, which is presumably due to the magnetic fields in these objects. Unfortunately there is currently

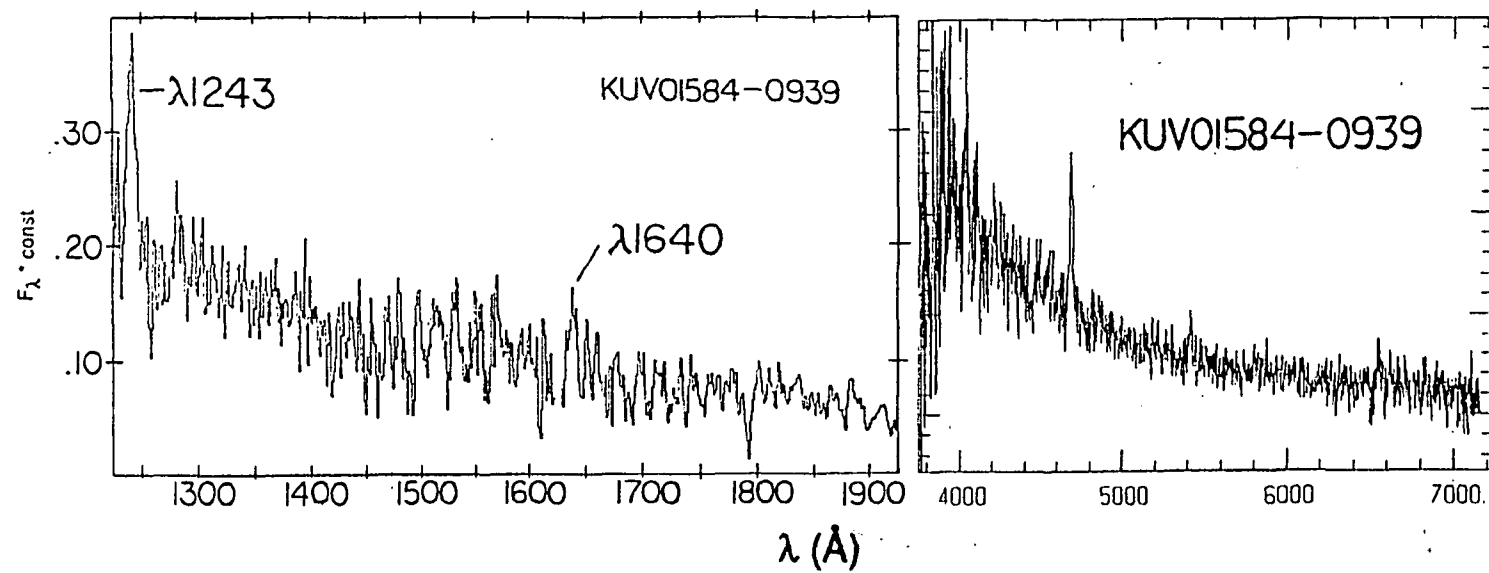


Figure 3: The ultraviolet (left) and visible portions of the spectrum of KUV01584-0939. The ultraviolet was observed with the IUE and data for the visible region were obtained with the McGraw-Hill 1.3 m telescope.

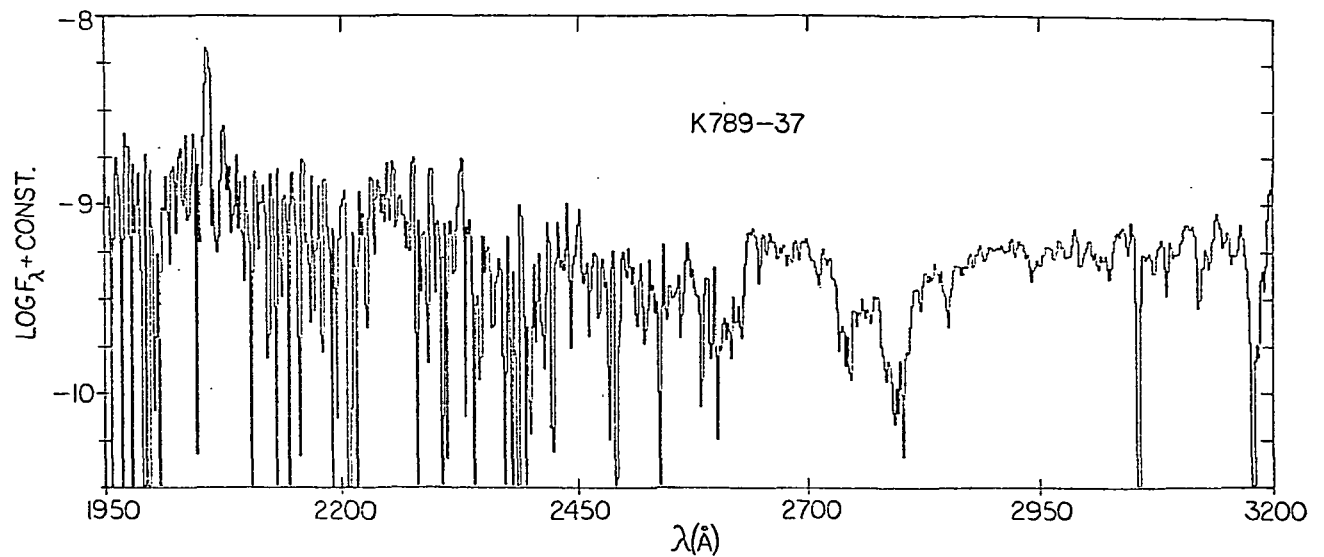
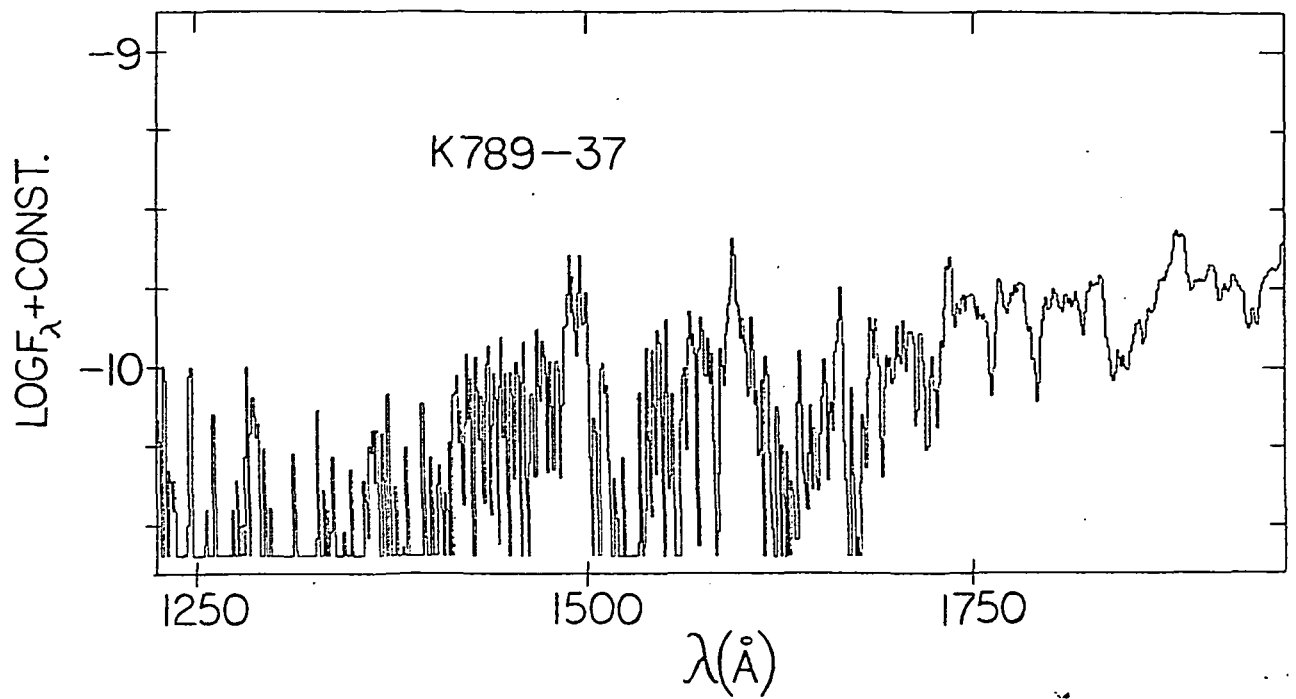


Figure 4: The ultraviolet spectrum of the DZA white dwarf K789-37 as observed with the IUE. The portion of the spectrum derived from the SWP image is at the top and that from the LWP is below. Note the richness of spectral features in the spectrum of this object.

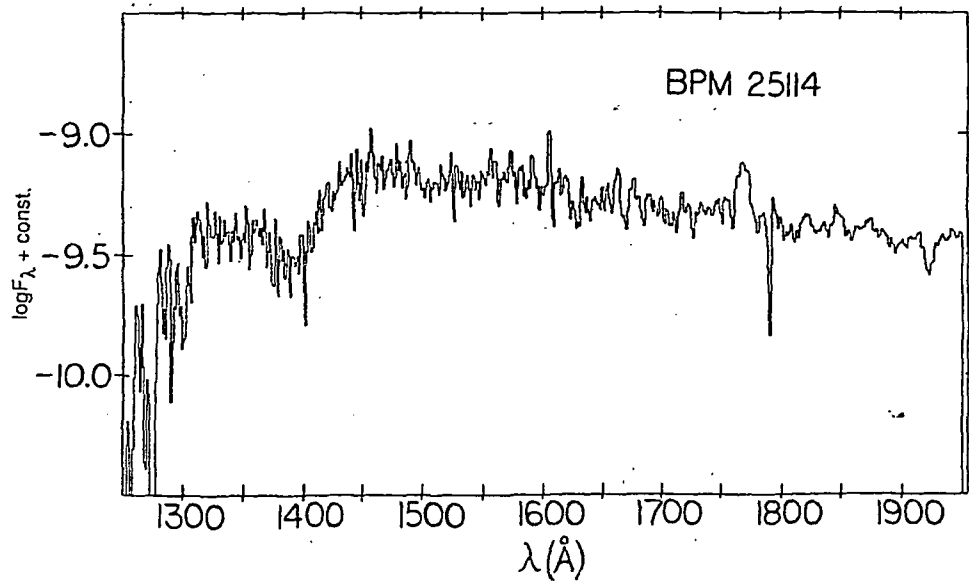
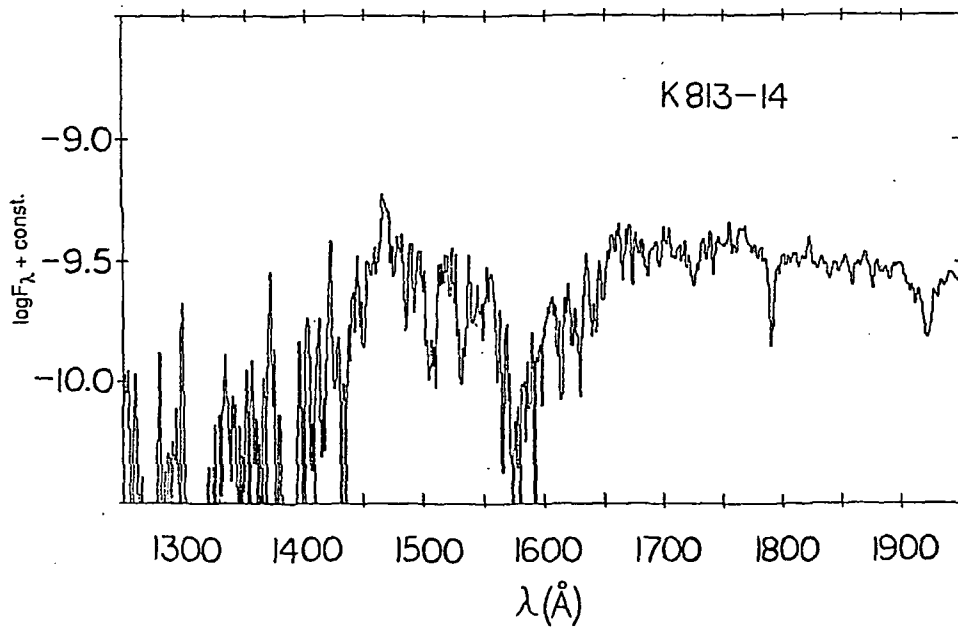


Figure 5: The SWP spectrum of the magnetic white dwarf BPM25114.

Figure 6: The same spectral region, but for the magnetic white dwarf K813-14.



no precise theory of how the quasi-molecular features should behave in a strong magnetic field.

VI. THE PECULIAR STAR HD159870 = HR 6560

One additional object studied was the peculiar star HD159870 = HR6560. The present IUE investigation of this object is the outgrowth of a collaboration on the visual spectrum in collaboration with C. R. Cowley at the University of Michigan. This star had been thought to be a possible example of a late-type metallic lined star which would have interesting implications for ideas on the origin of Ap and Am stars and thus on stellar evolution in general, as described, e.g. by Cowley and Bidelman (1979) and Cowley (1978). However from the IUE data, it was found that this object is a composite system which led to earlier wrong conclusions about its nature.

High and low resolution SWP and LWP spectroscopic observations with resolutions (approximately 0.1 Å and 7 Å respectively) were obtained of HD159870. All spectra are unwidened and the standard data reductions provided by NASA at the Goddard Space Flight Center were employed.

The low resolution mode was used to obtain the energy distribution of HD159870 from approximately 1400 Å to 3200 Å. A 30 mins. exposure, image no. SWP27164 taken through the large aperture of the spectrograph was saturated for wavelengths above λ 1600 but was combined with the large and small aperture spectra on SWP27165 which were both given 4 mins. of integration time and are well exposed up to λ 1950. The large and small aperture exposures of 57 secs. duration on image LWP7173 were combined to obtain the remainder of the energy distribution; the small aperture exposure was not utilized below λ 2250 as it becomes too noisy.

The high resolution echelle spectrogram of HD159870 proved important for studying the hot component of the system. Image no.

LWP7174 had an exposure time of 65 mins. and is well exposed over the wavelength interval $\lambda\lambda 2500-3000$.

The resulting ultraviolet spectral energy distribution of HD159870 from IUE is shown in Figure 7 where it is compared to two stars of known spectral type. This can be used to obtain a first approximation to the stellar makeup of the object. The overall drop in the ultraviolet is more comparable to the A5 V star as it can be seen that the energy distribution for G0 V drops considerably faster towards increasing $1/\lambda$. Certainly there is no evidence for an upturn in F_V at short wavelengths from a hot subluminous companion.

However this is inconsistent with the longer wavelength ground-based data. This can be better seen in Figure 8 by comparing the continuum energy distribution for HD159870 binned in approximately 50 Å windows compared to the same continuum points for single stars in the spectral range A0 - G0. The comparison stars were taken from Wu et al. (1983). The ground based photometry was converted to flux using the Vega calibration of Tüg et al. (1978). Reddening is expected to be small for all objects and has been neglected. At the accuracy of the present level of discussion, luminosity effects on the shapes of the energy distributions are unimportant and all objects shown are main sequence stars. In addition for HD159870, the ultraviolet photometry from the TD-1 satellite (Thompson et al. 1978) is shown. When the ultraviolet fluxes are compared with the VBU photometry, the V-band exceeds that to be expected from an extrapolation of the ultraviolet flux of an A5 star.

This demonstrates the composite nature of HD159870. Looking at the flatter part of the star's energy distribution in Figure 8 near $1/\lambda = 4 - 5$ and the declining portion for $1/\lambda > 5$, an A5 star gives a reasonably good fit to the ultraviolet energy distribution, but cannot follow the visual data. Alternately, a G0 energy distribution fits the visual flux data reasonably well but, as

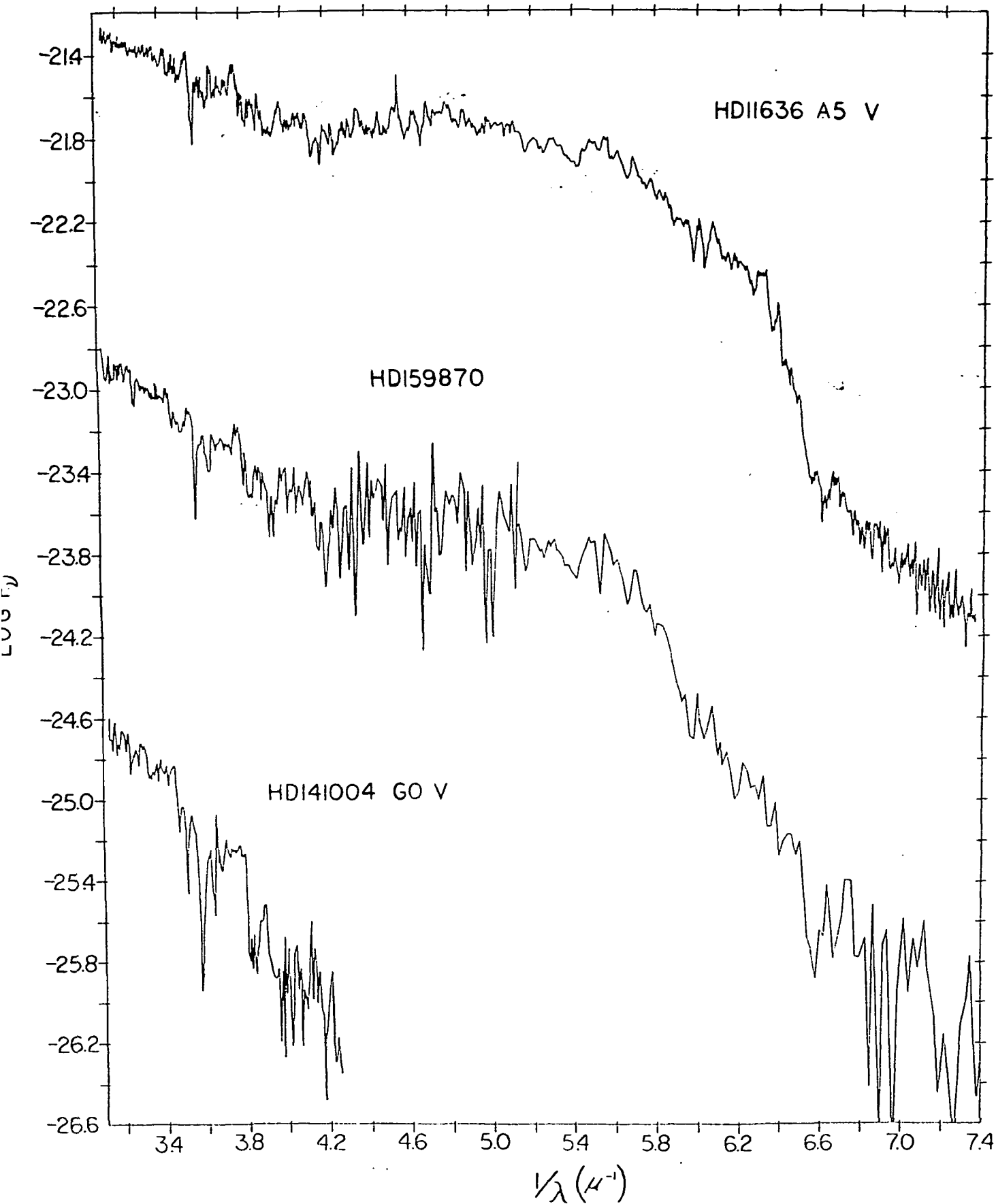


Fig. 7 - Comparison between the observed energy distribution of HD159870 and two normal stars of known spectral class.

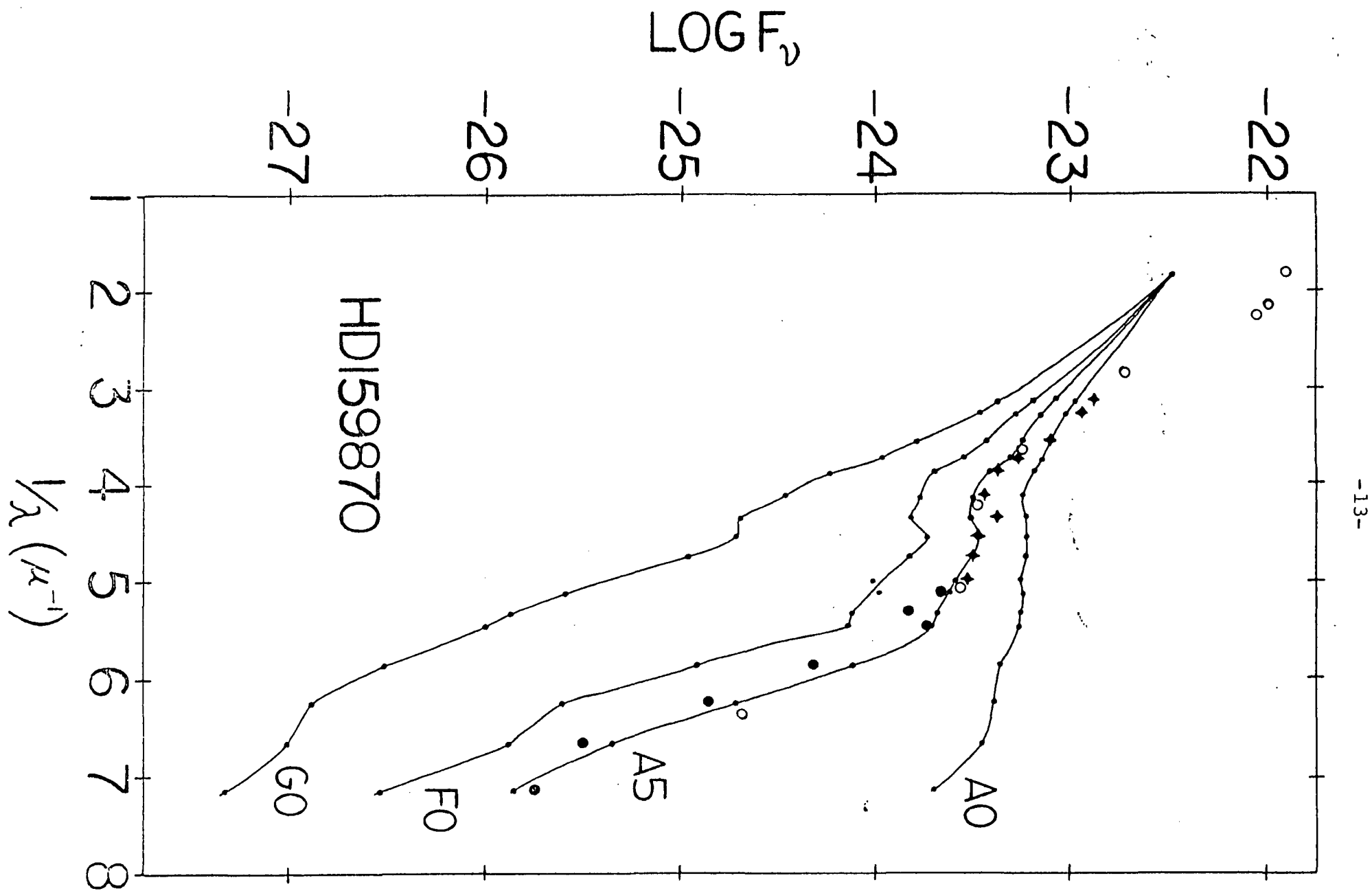


Fig. 8 - The binned energy distribution of HD159870 compared with those of main sequence stars.

already seen from Figure 7, declines too rapidly for $1/\lambda > 3$ to mimic the ultraviolet.

A composite system can produce the observed spectral energy distribution of HD159870. Figure 9 shows the sum of the A5 and G0 flux distributions compared with that of HD159870. With an A5 energy distribution fit to the ultraviolet, extrapolation to the visual gives $V = +7.6$ and assuming that the object lies on the main sequence with $M_V = +1.8$ yields a distance modulus of 5.8 magnitudes for the system. This in turn produces an absolute magnitude of $M_V = +0.4$ for the G0 component. That the G0 star lies above the main sequence agrees reasonably with the photometrically derived absolute magnitude of $M_V = +1.9$ to $+0.6$ from Strömgren photometry by Hauck and Mermilliod (1980) and the relations of Heck (1977) and is consistent with the high dispersion spectroscopy.

VII. DB STARS

A study of the ultraviolet and visual spectra of 27 DB helium atmosphere white dwarfs which took several years to complete has been published by Wegner and Nelan (1987). Visual wavelength and IUE ultraviolet spectra were used and a search was made for spectral lines of elements other than helium. Of the 15 DB stars studied with the IUE, the ultraviolet spectra failed to show any evidence for carbon and upper limits of $C:He < 10^{-5}$ to 10^{-7} were derived. These data were analyzed using model atmospheres and the comparison between observation and theory for some of the stars is shown in Figure 10. The lack of carbon was found to be consistent with the convective dredging theory for the origin of the carbon in the atmospheres of white dwarfs.

VIII. CONCLUSIONS

In general, the investigations with the IUE satellite described here have led to further understanding of the late stages of stellar evolution and in particular has increased knowledge of

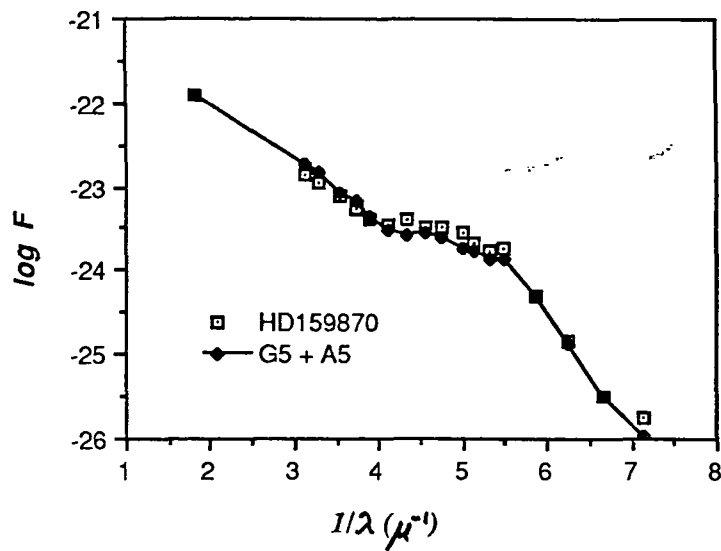


FIG. 9 - Comparison of the observed spectral energy distribution of HD159870 with an energy distribution of a composite star, obtained by adding the fluxes from a G5 III star and an A5 V star.

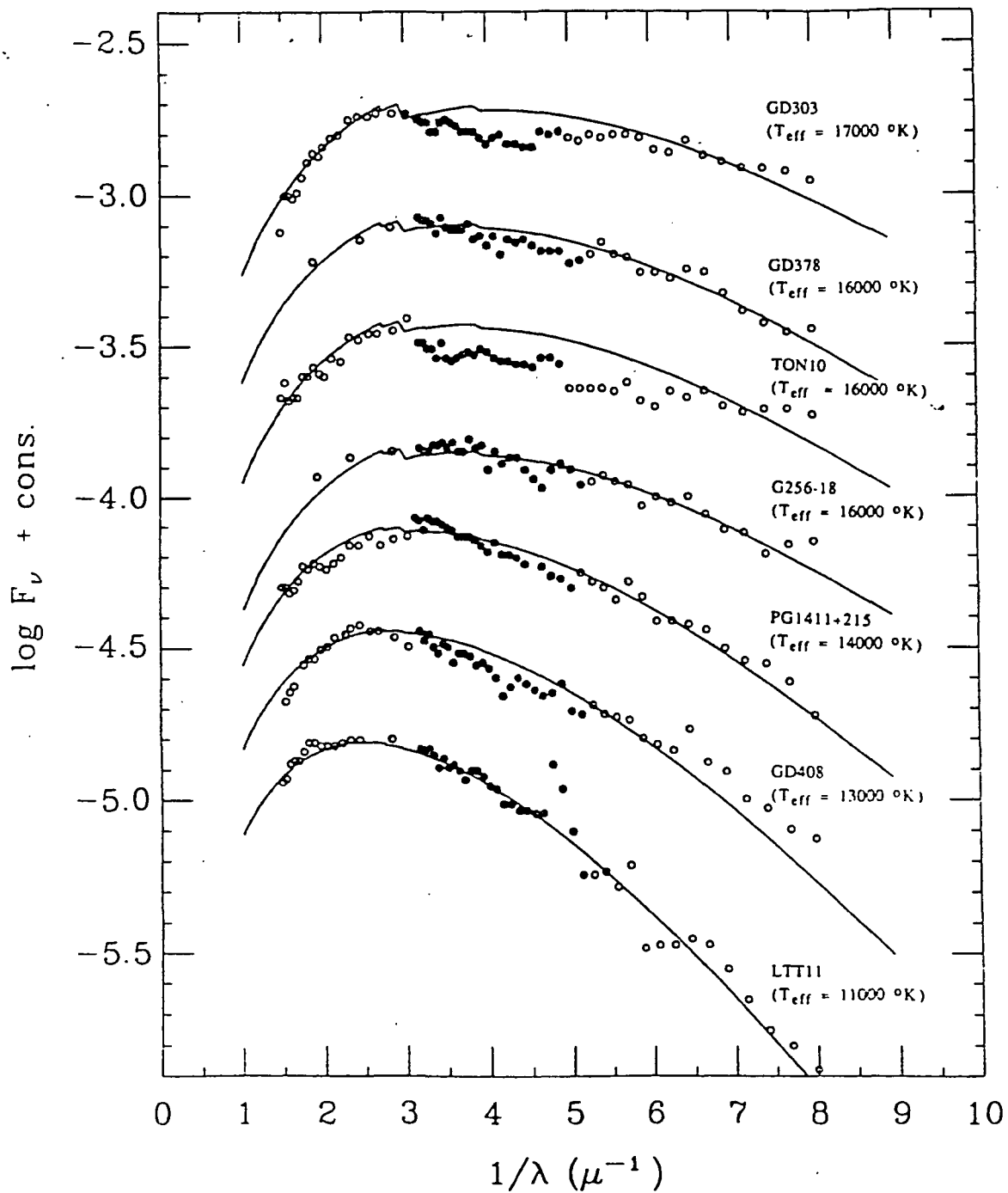


Figure 10- The observed continua of DB White dwarfs compared with model atmosphere calculations from Wegner and Nelan (1987) for helium-rich atmospheres with $\log g=8$.

the structure of the atmospheres of white dwarfs. The observations described above have produced new data on the absorptions near 1400 and 1600 Å in the ultraviolet spectra of the DA white dwarfs which become quite strong at lower temperatures. They are quite consistent with the explanation that they are quasi-molecular features of hydrogen and appear useful as a diagnostic for the atmospheric parameters of the DA white dwarfs and other high gravity hydrogen rich objects. It was the work carried out in Grant NAG5-287 which helped establish the nature of this phenomenon and to reach an explanation for it.

Corresponding studies of the helium rich DB white dwarfs have shown that no carbon lines appear in most of their ultraviolet spectra and that this is consistent with the process of convective dredging in their atmospheres. Further details of these processes, such as the metal lines in the spectrum of K879-37 and the magnetic DA stars have continued to give more detail on these mechanisms.

Besides giving the present information, these studies point the way for further investigations. Of particular interest will be observations of the ultraviolet spectra of the kinds of objects described in this report, but at much higher resolution and better signal to noise in order to make more detailed comparisons between the stars themselves and the model predictions as this will enable more accurate determinations of the atmospheric parameters for these stars plus giving the ability to search for even lower concentrations of metallic lines in their atmospheres which will produce more stringent limits on the processes that are important in the atmospheres of white dwarfs. Consequently, the IUE has laid a strong foundation for further studies that are anticipated with the Space Telescope.

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APPENDIX I. PUBLICATIONS PRODUCED UNDER NASA GRANT NAG5-287

Grant NAG5-287 was renewed yearly for the years 1984-1987.
The following is a list of research papers.

Liebert, J., Wesemael, F., Sion, E.M., and Wegner, G., "GD323, A White Dwarf with a Stratified H/He Atmosphere," Astrophys. J., **277**, 692 (1984).

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